Advances in Environmental Technology 4 (2020) 235-250

Iranian Reasearch Organization for Science and Technology (IROST)

Advances in Environmental Technology

Journal home page: https://aet.irost.ir/

Health risks assessment of heavy metal contamination in drinking water collected from different educational institutions of Khulna city corporation, Bangladesh

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ARTICLE INFO

Article history:
Received 25 May 2021
Received in revised form 16 July 2021
Accepted 20 July 2021

Keywords:
Heavy metals
Drinking water
Health risks
Khulna city corporation
Bangladesh

ABSTRACT

Clean and safe drinking water is indispensable for maintaining the sound health of humans. The presence of toxic elements in drinking water may cause harmful health effects. In this study, the concentrations of heavy metals in the drinking water of different academic institutions of the Khulna City Corporation (KCC) were determined using an atomic absorption spectrophotometer (AAS). The human health risks were assessed based on estimated daily intake (EDI), target hazard quotient (THQ), hazardous index (HI), and target cancer risks (TCR). The presence of the investigated heavy metals was in the following ranges: Fe (18.5–861.6 μg/L), Mn (0.020–0.564 μg/L), Zn (8.8–96.1 μg/L), Cu (5.6–52.9 μg/L), and As (<0.5–105.3 μg/L). About 52% of the drinking water samples for Mn and 12% for As surpassed the Bangladesh standard (BDS) value of 50.0 μg/L. On the other hand, the As concentration in 88% of the samples exceeded the guideline value of the World Health Organization (WHO) (10.0 μg/L). The analysis of the Pearson's correlation matrix (r) showed a positive correlation between Zn–Mn, Cu–Mn, Zn–Fe, Cu–Fe, and Fe–Mn at 0.01 levels and Zn–Cu and Fe–As at 0.05 levels, indicating the same pollution source. However, the THQ values of Zn, Cu, Fe, and Mn in all the studied samples were within the threshold risk limit (THQ < 1.0), and hence, safe from metal toxicity. But the THQ and HI of As for both adults and children and the TCR of As for adults in most of the investigated samples exceeded the maximum risk limit (THQ < 1.0; HI < 1.0; and TCR = 10^{-4}), which revealed As could be a potential source of carcinogenic and non-carcinogenic health risks. Therefore, regular monitoring of heavy metals should be carried out to assure good quality drinking water for the students and academic staff.

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DOI: 10.22104/AET.2021.4932.1331

1. Introduction

Water is the most important component for the existence of human life [1,2]. It plays an essential role in metabolism and the proper functioning of the cells [3]. Therefore, the supply of an adequate amount of clean and safe drinking water is the prerequisite for maintaining a sound life [1]. A significant number of people around the world use groundwater as the major source for drinking water and industrial, domestic, and agricultural activities [3]. About 90% of Bangladeshi people are directly dependent on a tube-well as the primary safe source of drinking water [4]. Over the last couple of decades, the dependency on groundwater resources has tremendously increased because of surface water contamination and rapid population growth [5]. Unfortunately, groundwater sources are being contaminated with different environmental pollutants from both natural and anthropogenic sources [4,6]. Among the various types of contaminants, the presence of heavy metals in the drinking water has become one of the most serious environmental issues due to their persistency, toxicity, and long-term bioaccumulation ability in the food chain [7]. Owing to improper agricultural practices, rapid urbanization, transportation, industrial activities, and natural geochemical processes, the concentration of heavy metals in the ecosystem is rapidly increasing [8-11]. Although some heavy metals such as manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe) are essential for triggering several biological applications in the human body, a high level of them may result in deleterious effects [12,13]. Contrarily, arsenic (As) has no role in metabolic activities, and hence, it is considered a non-essential toxic metal [13]. It has been reported that As is responsible for cancers, arsenicosis, melanosis, hyperkeratosis, hepatocellular carcinoma, diabetes mellitus, hypertension, liver fibrosis, cirrhosis, and parenchymal cell damage [2,4,9]. Mn is well known for exerting neurotoxic effects, especially in children [4,14]. The intake of elevated amounts of Fe can cause vomiting and diarrhea along with a posterior effect on the liver, kidney, blood, cardiovascular, and central nervous systems. Subsequently, Zn reduces the concentration of high-density lipoproteins and inhibits the proper functioning of the immune system. Long-term intake of Zn may also cause anemia and vomiting with other health effects [4,14]. Similarly, the consumption of drinking water containing Cu may cause Alzheimer's disease [13]. A survey of previous literature indicates that heavy metal concentration in drinking water varies from region to region. Sultana et al. [15] reported that the drinking water samples of some educational institutions in the Tangail Municipality contained a higher level of Fe, and hence, unsuitable for drinking. In a similar study, Sunjida et al. [1] found an excess amount of heavy metals in the drinking water from the Tongi Industrial Zone of Bangladesh. The findings of Rahman et al. [14] indicated that the concentration of As, Fe, and Mn in the tube-well water of the primary schools in the Magura district did not meet WHO and BDS standards. Islam et al. [9] evaluated the drinking water quality in the Rangpur district of Bangladesh. They showed that the mean concentrations of Mn and Fe exceeded the permissible limits, and the concentrations were hazardous to human health. In another research, Islam et al. [16] reported that As was the most dominant element in the drinking water of the Sylhet district, Bangladesh. In 2018, Rahman and Hashem [17] explored the status of drinking water quality in some primary schools in the Satkhira district, Bangladesh. Their results indicated that the As and Fe content in 49% and 45% of the samples, respectively, exceeded the WHO guideline. Again, Rahman et al. [4] monitored the drinking water quality in Assasuni Upazila, Satkhira, Bangladesh, and reported that the As content surpassed both the WHO and BDS standards. Furthermore, Ahmed et al. [18] found that the arsenic in 40% of the groundwater samples in Rupsha Upazila, Bangladesh was above the BDS standard. Several researchers in Bangladesh have primarily focused on the health risk assessment of households and the community-based surface and groundwater [19-21]. But only a few studies are available that have investigated heavy metal contamination in the drinking water of academic institutions [22]. Drinking water from these institutions could be a possible source of heavy metal exposure because the students and staff stay from ~9.00 am to ~4.00 pm and drink an adequate amount of water. Safe drinking water is necessary for the student's proper growth and development and mental health [14,17]. If they consume contaminated water, they may experience serious health effects. Hence, it is our prime concern to ensure safe drinking water for the study population and to assess the water quality before consumption. To the best of our knowledge, no previous article has been published regarding the contamination status of heavy metals in the drinking water of different academic institutions of KCC. Being the third-largest economic center in Bangladesh, KCC has several schools, colleges, and universities with a large number of students and faculty. The emphasis of this research was on the health risks to this group. Therefore, the main objectives of the present study were (a) to determine the concentration of heavy metals (As, Mn, Cu, Zn, and Fe) in the drinking water of different academic institutions of KCC, (b) to evaluate principal component analysis (PCA) and Pearson's correlation matrix among the studied heavy metals, and (c) to assess the health risks of children and adults based on the USEPA deterministic model. The USEPA deterministic model is an important tool for determining the health risks of humans [4,22]. This model includes four basic steps, namely hazard identification, hazard characterization or dose-response assessment, exposure assessment, and risk characterization [23]. Hazard identification initially investigates which toxic elements are present in the target samples. Hazard characterization or dose-response assessment measures the toxicity and exposure levels of carcinogenic and non-carcinogenic heavy metals based on the carcinogenic potency slope factor (CPSF) and oral reference dose (RfD) indices. The exposure assessment estimates the frequency, duration, and intensity of human exposure to a toxicant in terms of measured EDI values [24–26]. Lastly, risk characterization qualitatively or quantitatively determines the probability of developing carcinogenic and non-carcinogenic health effects among the study population by integrating all the information gathered from the previous three steps [23,24]. In this study, the non-carcinogenic health risk was estimated based on the EDI, THQ, and HI approach; the carcinogenic risk was calculated by TCR analysis.

2. Materials and methods

2.1. Study area

The study area (KCC) is the divisional headquarter of the Khulna division and an expanding commercial center in Southwestern Bangladesh [27]. This city is located at 22°46′ to 22°58′ North latitude and 89°28′ to 89°37′ East longitude (Figure 1) [28]. The Rupsa River on the middle side, Bhairab River on the northern part, and Pasur River on the southern side flow along the eastern margin of the city. The Mayur River on the northern side and the Hatia River on the southern part flow along the western side of the city [27,28]. The city currently comprises an area of 46 sq. km, and the soil is composed of silt, sand, and clay in various proportions with a small amount of coarse sand [27,28].

2.2. Sample collection

In January 2020, drinking water samples were collected from twenty-five different academic institutions in KCC, Bangladesh. The sampling stations were selected in such a way that it represents the entire area of KCC. For sampling purposes, plastic bottles of 500 mL capacity were used. These bottles were previously cleaned and washed with detergent, followed by rinsing with tap water and deionized water. Before sampling from the tube well, a sufficient quantity of water was pumped out so that the sample represented the groundwater [4,27]. After sampling, each drinking water sample was acidified with conc. HNO_3 acid (Merck, Germany) and filtered through a Millipore cellulose membrane (0.45 μm) to avoid any unwanted impurities [4]. Usually 1.5 mL conc. HNO_3/L sample is adequate for short-term preservation [29]. The collected samples were preserved in the refrigerator at 4 °C for further use. A brief description of the sample sites, water sources, and coordinates of sampling points are shown in Table 1.

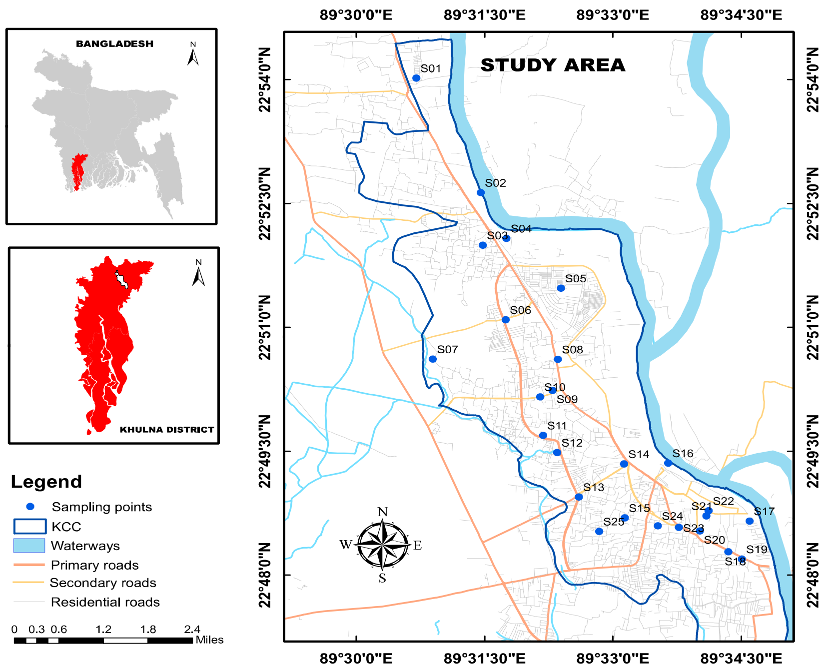


Fig. 1. Map of the study area (KCC, Bangladesh).

Table 1. A brief description (Sample code, Latitude, Longitude, and Source) of the sampling stations.

Sample code	Sampling points	Latitude (° N)	Longitude (° E)	Source
DW1	K. D. A. Khanjahan Ali High School	22.900323	89.511679	TW
DW2	Government Daulatpur Muhsin High School	22.877204	89.524226	TW
DW3	Daulatpur College (Day/Night)	22.866594	89.524611	TW
DW4	Govt. B.L. College	22.867997	89.529253	TW
DW5	Maulana Vasani Bidyapith Girls School & College	22.857923	89.539865	TW
DW6	Bangladesh Navy School & College	22.851536	89.529097	TW
DW7	Rayermahal Degree College	22.843631	89.514886	TW
DW8	Imperial College of Engineering	22.843555	89.539249	FW
DW9	Khulna Govt. Girls College	22.837299	89.538204	TW
DW10	PMG High School	22.835966	89.535795	TW
DW11	Khulna Medical College	22.828234	89.536366	TW
DW12	Joy Bangla College	22.824737	89.539118	TW
DW13	North Western University	22.815764	89.543363	FJW
DW14	Northern University of Business and Technology	22.822445	89.552148	FJW
DW15	Islamabad Collegiate School	22.811591	89.552285	TW
DW16	Rupsha High School	22.822626	89.56073	TW
DW17	Fatima High School	22.810919	89.576604	TW
DW18	Govt. Sundarban Adarsha College	22.804727	89.572466	TW
DW19	KCC Women's College	22.803235	89.575104	TW
DW20	St. Joseph High School	22.808905	89.566894	TW
DW21	Azam Khan Govt. Commerce College	22.811956	89.568177	TW
DW22	Govt. Model High School	22.812996	89.568623	TW
DW23	Govt. M.M. City College	22.809658	89.562828	TW
DW24	Govt. Iqbalnagar High School	22.80998	89.558709	TW
DW25	Shahid Suhrawardi College	22.808828	89.547298	TW

TW= Tube well water, FW= Filtered water, FJW= Filtered jar water.

2.3. Sample analysis

The sample preparation and analysis steps were carried out based on the standard methods of the American Public Health Association (APHA) [29]. As stated by the APHA, the samples which are colorless and transparent (primarily drinking water) may be analyzed without digestion (APHA method no. 3030A) [29]. Therefore, the concentrations of Mn, Fe, Cu, and Zn in previously acidified samples were determined directly by the flame-AAS method (AA-7000, Shimadzu, Tokyo, Japan). On the other hand, the concentration of As was analyzed through the hydride vapor generation (HG-AAS) technique (APHA method no. 3114B) [4,29]. Before sample analysis, the calibration curve of Mn, Fe, Cu, Zn, and As was constructed at the wavelengths of 279.5, 248.3, 213.9, 324.8, and 193.7 nm, respectively, by diluting the standard solutions (Wako Chemicals, Japan). Then, the contamination level of the heavy metal was calculated from the calibration curve [4,29]. Argon was used as the career gas to determine As, while Air–acetylene was used to quantify other metals. The limit of detection (LOD) for Mn, Fe, Cu, Zn, and As was respectively 1.6, 5.2, 1.0, 2.6, and 0.5 μg/L; their limit of quantification (LOQ) was 4.8, 15.6, 3.0, 7.8, and 1.5 μg/L, respectively. For analytical quality control, the replicate analysis of the heavy metals was performed; one standard sample was analyzed at the intervals of five experimental samples to ensure the accuracy of the results. The recovery percentages of the internal standard solutions ranged from 94.5 to 102.7%.

2.4. Statistical analyses

To specify the inter-relationships among the studied heavy metals and their possible source of contamination, multivariate statistical analyses such as Pearson's correlation and principal component analysis (PCA) were performed using IBM SPSS software, version 26.0. The graphs were generated using GraphPad Prism 8.0.1 software for windows.

2.5. Health risks assessment

The USEPA Region III risk-based table was used to estimate the probabilistic health risks of the study population [30,31]. At first, the EDI of individual heavy metals was determined by using Eq. 1.

$$EDI = \frac{CM \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

$$THQ = \frac{CM \times IR \times EF \times ED}{BW \times ATn \times RfD} \quad (2)$$

$$HI = \Sigma THQ \quad (3)$$

$$TCR = \frac{CM \times IR \times EF \times ED \times CPSF}{BW \times ATc} \quad (4)$$

After that, the non-carcinogenic health risks (THQ and HI) and the carcinogenic health risks (TCR) were determined based on Eq. 2–4 [5,31]. The general description of risk assessment parameters and the meaning of each symbol with reference values are provided in Table 2. The overall research methodology has been summarized in Scheme 1.

3. Results and discussion

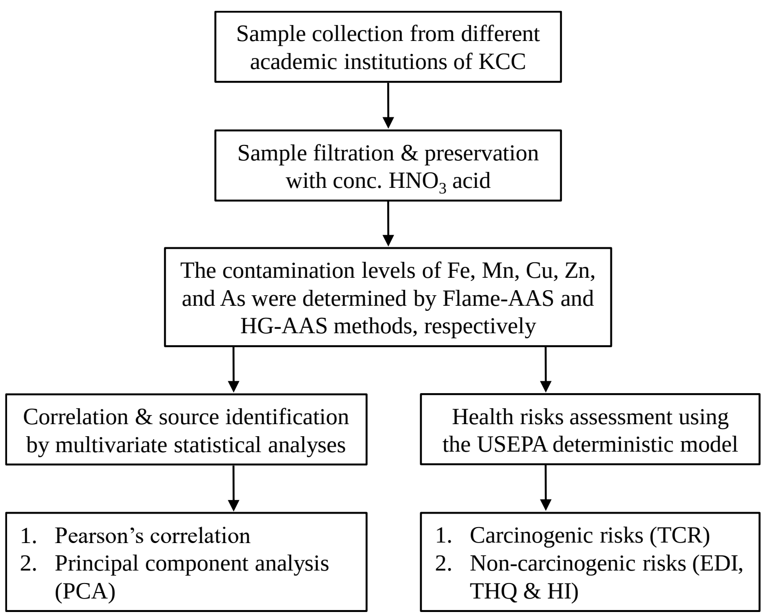
3.1. Heavy metal concentration in drinking water samples

Figure 2a presents the descriptive statistics (DS) data of heavy metals in the analyzed drinking water samples. The mean concentration (μg/L) of the heavy metals showed a descending order of Fe > Mn > Zn > As > Cu. The median and mean concentrations of Fe in the drinking water samples were 281.7 μg/L and 355.1±260.6 μg/L, respectively, and ranged between 18.5 μg/L and 861.6 μg/L. The average value of Fe was found to be within the standard guideline value of the WHO (1000 μg/L) and BDS (300–1000 μg/L) as illustrated in Figure 2(a, b) [21,33,34]. However, the mean concentration of Fe was almost similar to the previously reported value of 345.2 μg/L in Dinajpur [21] and higher than that of 3.3 μg/L in Noakhali [35]. Contrarily, the mean value was much lower than the reported data of Fe in Satkhira (3593.0 μg/L) [4], Lakshimpur (3235.0 μg/L) [7], Rangpur (7726.5 μg/L) [9], Magura (1246.5 μg/L) [14], Jashore (1400 μg/L) [36], and Faridpur (5951.6) μg/L [37] district of Bangladesh (Table 3).

Table 2. General description of health risk assessment parameters.

Symbol	Description	Unit	Value (for children)	Value (for adults)
CM	Concentration of metals	μg/L	-	-
IR	Ingestion rate	L/day	¥0.75	¥2.0
BW	Average body weight	kg	30 (approx.)	60 (approx.)
EF	Exposure frequency	days	250 (Excluding holidays and weekends)	
ED	Exposure duration	years	#12	@40
AT	Average time	days	#12×365	@40×365
ATn	Average time (non-carcinogen)	days	#12×365	@40×365
ATc	Average time (carcinogen)	days	*67×365	$48×365
CPSF	carcinogenic potency slope factor	$(\mu g/kg\text{-}day)^{-1}$	As=0.0015 [31]	
RfD	Oral reference dose	μg/kg-day	Fe= 700, Zn=300, Mn=140, Cu=40, and As=0.3 [31]	

¥The ingestion rate was confirmed during the field survey by asking the students, and staff of academic institutions.
Generally, a child goes to school at the age of 6 years and they continue the study from class-1 to class-12. Thus, the exposure duration for children was considered 12 years.
@ An adult starts to serve as an academician or staff at the age of ~25 years and the service limit ends at the age of 65. Therefore, the exposure duration for an adult was considered (65–25) = 40 years for non-carcinogenic health risk assessment.
*,$ The average life expectancy of a Bangladeshi person is 73 years [32]. So, the average lifetime (carcinogenic) was assumed 73–6 = 67 years for children, and 73–25= 48 for adults.



Scheme 1. A flow diagram of the overall research process.

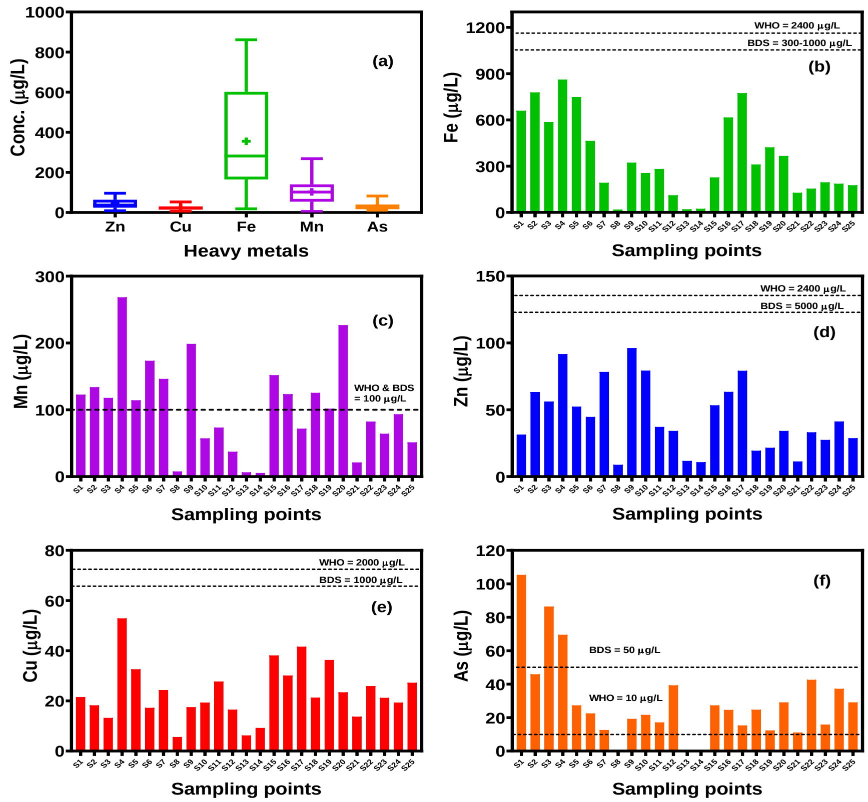


Fig. 2. (a) Box plot indicating minimum, maximum, median, mean, 1st and 3rd quartile (b-f) Heavy metal concentration (μg/L) of individual sampling points of KCC.

The Mn content ranged between 5.3–268.3 μg/L with a median and average concentration of 101.7 μg/L and 102.9±68.1 μg/L, respectively. In this study, 52% of the drinking water samples (DW1–DW7, DW9, DW15, DW16, and DW18–DW20) surpassed the WHO and BDS permissible limit of 100 μg/L [33,34] (Figure 2a and 2c). However, the average value was comparatively lower than the reported concentrations of Mn in previous studies of different areas in Bangladesh, except the groundwater at Faridpur (Table 3). The median and mean concentration of Cu in the drinking water samples observed were 21.3 μg/L and 23.2±26.0 μg/L, respectively, and ranged between 5.6–52.9 μg/L. In this study, none of the experimental samples were beyond the standard guideline value recommended by the WHO (2000 μg/L) [33] and BDS (1000 μg/L) [34] (Figure 2a and 2d). The average concentration of Cu in the drinking water was lower than the previously reported value of 50.0 μg/L in Gazipur [1] and 37.5 μg/L in Dinajpur [21], and higher than that of 4.5 μg/L in Noakhali [35] and 7.76 μg/L in Chattagram [38] (Table 3). In this investigation, Zn content varied from 8.8 μg/L to 96.1 μg/L with the mean and median value of 44.3±26.0 μg/L and 37.1 μg/L, respectively. The BDS and WHO acceptable value for Zn is 5000 μg/L and 2400 μg/L, respectively; it was found that all the examined samples were within these guideline values (Figure 2a and 2e) [33,34]. However, the mean Zn concentration was almost similar to the reported value of 33.3 μg/L in Rangpur [9], 37.4 μg/L in Noakhali [35], and 38.0 μg/L in Satkhira [4]. Contrarily, this concentration was much lower than the published value of Zn in Gazipur (330.0 μg/L) [1] and higher than that of 10.38 μg/L in Faridpur [37], 15.6 μg/L in Dinajpur [21], and 22.0 μg/L in Lakshimpur [7], as presented in Table 3. The concentrations of As in the drinking water samples varied from <0.5 μg/L to 105.3 μg/L with the average and median values of 33.4±24.6 μg/L and 26.0 μg/L, respectively. The WHO and BDS maximum guideline value of As in the drinking water is 10 μg/L and 50 μg/L, respectively [33,34]. Although the concentrations of As in 88% of drinking water samples (except DW1, DW3, and DW4) were within the permissible limit of BDS standard, all the studied samples exceeded the

WHO guideline value (Figure 2a and 2f). In this investigation, the average concentration of As was higher than the drinking water consumed in Magura (4.25 µg/L) [14] and Rangpur (8.8 µg/L) [9], but lower than that of Noakhali (297.5 µg/L) [35], Lakshimpur (85.0 µg/L) [7], Faridpur (118.6 µg/L) [37], Gazipur (890.0 µg/L) [1], and Satkhira (57.0 µg/L) [4], as shown in Table 3.

Table 3. Comparison of heavy metal concentration (µg/L) in drinking water with similar studies.

Study area	Fe	Mn	Cu	Zn	As	Reference
Gazipur	–	124.9	50.0	330.0	890.0	[1]
Satkhira	3593.0 80.0–7520.0	143.0 20.0–564.0	–	38.0 10.0–239.0	57.0 1.0–214.0	[4]
Lakshimpur	3235.0 122–2480.0	652.0 51.0–3830.0		22.0 2.0–82.0	85.0 <LOD –404.0	[7]
Rangpur	7726.5 47.0–22400.0	684.8 85.0–4960	–	33.3 6.0–234.0	8.8 0.5–42.8	[9]
Magura	1246.5 30.0–3790.0	144.0 20.0–660.0	–	–	4.25 <LOD –12.0	[14]
Dinajpur	345.2 96.4–735.2	406.9 49.4–1661.0	37.5 13.9–55.1	15.6 2.1–100.4	–	[21]
Noakhali	3.3 0.05–9.0	139.6 18.9–499.5	4.5 <LOD –114.2	37.4 <LOD –359.5	297.5 1.5–587.6	[35]
Jashore	1400 20–6200	470 16–2108	–	–	–	[36]
Faridpur	5951.6 52.0–19600.0	0.64 0.04–4.23	–	10.38 2.0–58.0	118.6 8.0–1460.0	[37]
Chattagram	<LOD	<LOD	7.76 5.02–10.55	<LOD	<LOD	[38]
KCC	355.1 18.5–861.6	102.9 5.3–268.3	23.2 5.6–52.9	44.3 8.8–96.1	33.4 <0.5–105.3	Present study

3.2. Pearson's correlation matrix (r) analysis

Multivariate statistical analysis is an appropriate technique that helps identify the possible source of origin of hazardous metals and establish the specific relationship among the studied variables [7,20]. The Pearson's correlation matrix is generally employed to illustrate the influence of studied variables on drinking water quality. The values of coefficient (r) and their strength of correlation can be categorized as follows: (i) very weak correlation (r=0.0-0.2), (ii) slightly significant correlation (r=0.2-0.4), (iii) moderate correlation (r=0.4-0.6), (iv) strong correlation (r=0.6-0.8), and (v) very strong correlation (r=0.8-1.0) [20]. Table 4 shows the strong-moderate positive correlation between Zn–Fe (r=0.576), Zn–Mn (r=0.619), Fe–Mn (r=0.596), Cu–Mn (r=0.541), and Cu–Fe (r=0.598) at 0.01 levels, and Zn–Cu (r=0.504) and Fe–As (r=0.438) at 0.05 levels, indicating these metals might be originated from the same pollution source. Generally, a higher amount of Fe may get into groundwater from geogenic sources. Mn in the groundwater occurs naturally as a mineral from sediment and rocks [5]. Cu and Zn can be assimilated through the discharge of industrial effluents and domestic wastes in the water, mineral leaching, and excessive use of fertilizers and agrochemicals [5,7,37]. However, no correlation was observed between Zn–As, Cu–As, and Mn–As, suggesting that these metals might originate from geogenic or multiple anthropogenic sources such as improper sanitation, agriculture activity, organic decomposition, etc. [20].

Table 4. Pearson's correlation coefficient (r) matrix among the different metals.

	Zn	Cu	Fe	Mn	As
Zn	1				
Cu	.504*	1			
Fe	.576**	.598**	1		
Mn	.619**	.541**	.596**	1	
As	0.053	-0.029	.438*	0.252	1

*Level of significance: ** at 0.01 level, * at 0.05 (2 tailed).*

3.3. Principal component analysis (PCA)

In recent times, PCA has become one of the most popular tools for illustrating the ecological aspects of pollutants in the ecosystem [19]. It is also widely used to predict the source of heavy metals and to show the correlation among the different variables. The overall summary of the components of PC1 and PC2, including the eigenvalues, factor loadings, percentage of the cumulative variance, and total variance, are presented in Table 5.

Table 5. Results of extracted Eigenvectors for PCA of heavy metals.

Elements	Components of	Components of
Zn	0.709	-0.305
Cu	0.633	-0.464
Fe	0.833	0.2
Mn	0.770	-0.027
As	0.423	0.861
Eigen values	2.37	1.09
% of	47.36	21.81
Total	69.17 (approx.)	

According to Shrestha and Kazama [39], the factors having the highest eigenvalues (≥1.0) are the most significant. In this study, the eigenvalues of PC1 and PC2 were found to be 2.37 and 1.07, respectively. Besides, PC1 and PC2 explained approximately 47.36% and 21.81% of the total variance (69.17%), which indicated that the first factor (PC1) was strongly correlated with the variables than the second factor (PC2). To illustrate the strength of correlation among the variable pairs, the PCA can be categorized into weak, moderate, and strong, based on the factor loading values of 0.50 to 0.30, 0.75 to 0.50, and >0.75, respectively [19,40]. Moreover, when the two variables are far from the center and nearest to each other, they have a significant positive correlation (r ≈ 1) [41]. Table 5 and Figure 3 indicate that PC1 had strong positive loading factors on Zn, Fe, and Mn, moderate loadings on Cu, and weak loadings on As. Subsequently, PC2 had a strong positive loading factor on As and a weak negative loading on Zn and Cu.

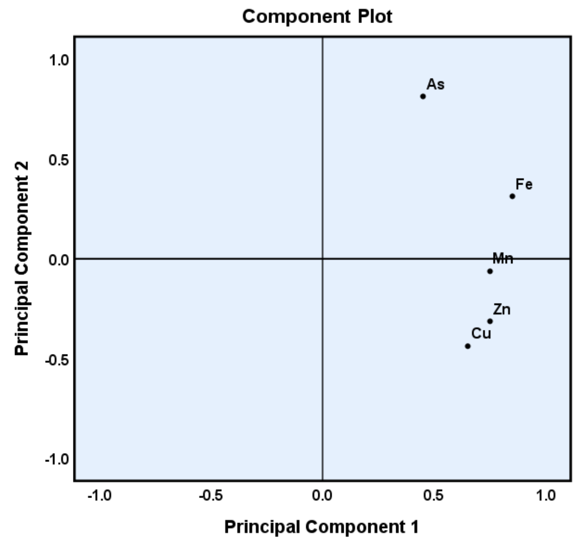


Fig. 3. PCA of heavy metals in water samples.

3.4. Non-carcinogenic health risk assessment

The descriptive statistical (DS) data of EDI due to the intake of drinking water for the study population are shown in Figure 4 (a-j). The mean EDI values of Zn, Cu, Fe, Mn, and As for the students were 0.759±0.446, 0.397±0.190, 6.081±4.462, 1.763±1.165, and 0.573±0.419 μg/kg–BW–day, respectively, and ranged from 0.151–1.646, 0.096–0.906, 0.317–14.753, 0.091–4.594, and 0.190–1.803 μg/kg–BW–day, respectively. Contrariwise, the EDI values of Zn, Cu, Fe, Mn, and As for adults ranged from 0.201–2.194, 0.128–1.208, 0.422–19.671, 0.121–6.126, and 0.253–2.404 μg/kg–BW–day, with the mean concentration of 1.011±0.594, 0.530±0.253, 8.108±5.945, 2.350±1.554, and 0.764±0.559 μg/kg–BW–day, respectively.

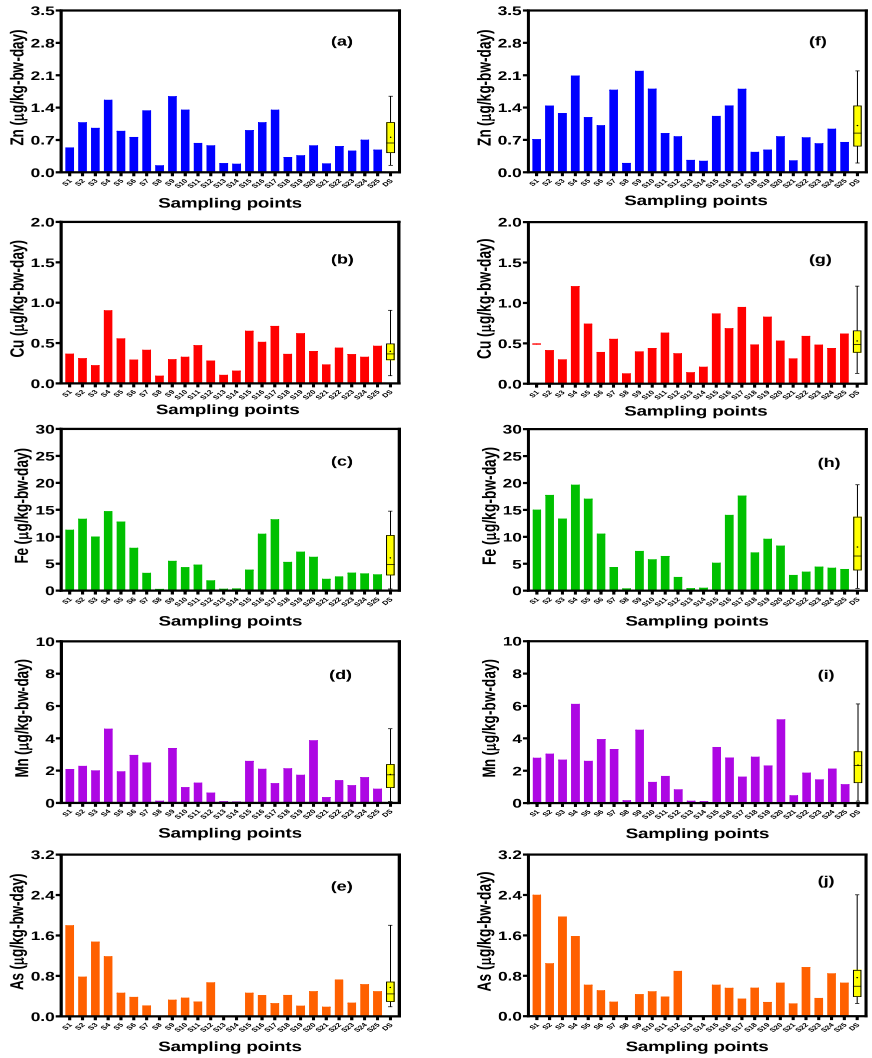


Fig. 4. EDI (µg/kg–BW–day) of studied heavy metals (a-e) for children and (b-j) for adults.

The decreasing order of EDI among the studied metals was Fe > Mn > Zn > As > Cu. In this current study, the EDI values of each heavy metal have been compared with the corresponding RfD value. The New York State Department of Health suggested that if the ratio of EDI and RfD is less than or equal to 1.0, there are no risks [42]. As shown in Figure 4, the reference dose of Fe, Zn, Mn, Cu, and As is 700, 300, 140, 40, and 0.3 µg/kg-day, respectively [31]. By comparing all the above groups, the ratio of EDI/RfD for Fe, Zn, Mn, and Cu was less than 1.0, which indicated that both the adults and children would not experience potential health risks due to these metals. But, the ratio of EDI/RfD for As in most of the samples for both the adults and children was greater than unity. Therefore, the presence of As in drinking water could be a matter of non-carcinogenic health concern for the study population, as revealed by the EDI analysis. THQ is the ratio of the EDI and oral reference dose (RfD) of the corresponding heavy metals. If the value of THQ for the individual heavy metals falls below 1.0, the exposed people are safe from any kind of non-carcinogenic health risks. On the other hand, if this ratio is > 1.0, it may pose detrimental health effects [30,31]. Figure 5 (a-j) represents the THQ values of individual heavy metals due to consumption of drinking water for both children and adults. The average THQ values of Zn, Cu, Fe, Mn, and As were respectively 0.003±0.001, 0.010±0.005, 0.009±0.006, 0.013±0.008, and 1.909±1.397 for the students and 0.003±0.002, 0.013±0.006, 0.012±0.008, 0.017±0.011, and 2.545±1.862 for the adults. However, the THQ values of Zn, Cu, Fe, and Mn in all the studied samples were within the threshold risk limit (THQ < 1). But, the THQ value of As in 64% of the samples (DW1-DW6, DW9, DW10, DW12, DW15, DW16, DW18, DW20, DW22, DW24, and DW25) for children and 76% of the adult samples (DW1–DW6, DW9–DW12, DW15–DW18, DW20, and DW22–DW25) exceeded the maximum risk limit, which indicated As could be a possible source of non-carcinogenic health risks.

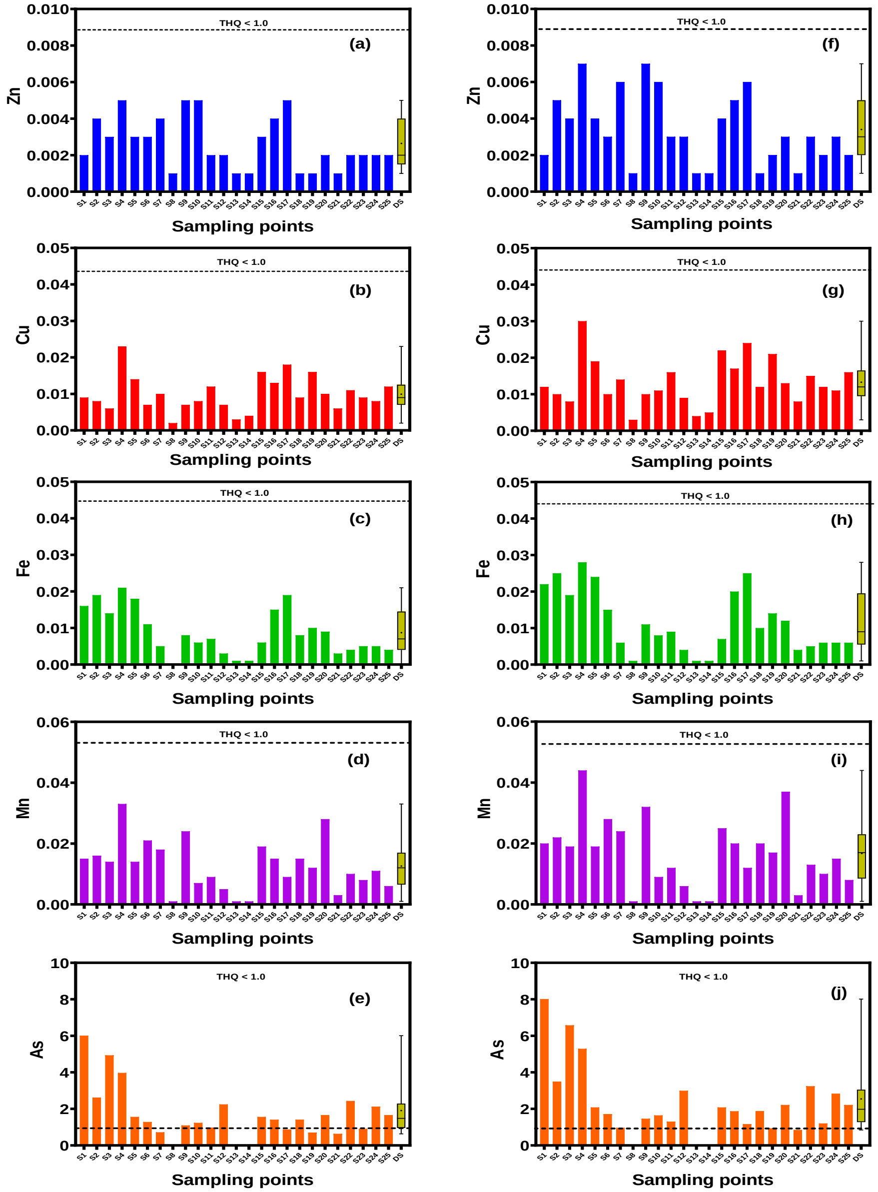


Fig.5. THQ of different heavy metals for (a-e) children and (f-j) adults.

In a study, Rahman and Hashem [17] reported that the mean THQ values of As in the drinking water of Kaliganj, Tala, Kalaroa, Satkhira proper, Asasuni, Shymnagar, and Debhata were 6.34187, 5.4676, 5.9024, 3.47823, 2.8167, 1.7391, and 1.03533, respectively, which was almost similar to the mean value of the present findings. In another study, Rahman et al. [4] found the mean THQ results of As, Mn, and Zn in the drinking water samples of the Assasuni Upazila in the Satkhira district, Bangladesh, were 9.4937, 0.0511, and 0.0096 for the adults and 28.4810, 0.1533, and 0.0192 for the children, respectively. Among these metals, the THQ data for As for both children and adults surpassed the threshold risk limit (1.0). Similarly, Rahman et al. [22] reported that the average THQs from As intake was higher than unity for children in all the studied districts (Narail, Bagerhat, Sathkhira, Khulna, and Jashore). When the population is exposed to more than one toxicant, the hazardous index (HI) can be obtained by simply adding the THQ of all the investigated heavy metals. If the value of HI is less than 1.0, the individual is safe from non-carcinogenic health risks [30]. The presented data in Figure 6 show that the HI value in 68% of the samples (DW1–DW6, DW9–DW12, DW15, DW16, DW18, DW20, DW22, DW24, and DW25) for the children and 80% of the samples (DW1–DW7, DW9–DW12, DW15–DW18, DW20, and DW22–DW25) for adults were beyond the recommended threshold risk limit of HI < 1.0, which is a matter of health concern. However, the HI values of the children and adults ranged between 0.004 to 6.050 and 0.006 to 8.070, respectively, with the mean values of 1.714±1.460 and 2.285±1.947. Recently, Ghosh et al. [36] reported that the HI values for adults in 39% of samples and 3% of the children samples exceeded the maximum risk limit in Jashore, Bangladesh. In a previous study, Rahman et al. [4] reported that the average values of HI for children and adults were 28.6535 and 9.5512, respectively, in the drinking water of the Assasuni Upazila of Satkhira district, Bangladesh, which was much higher than the present study.

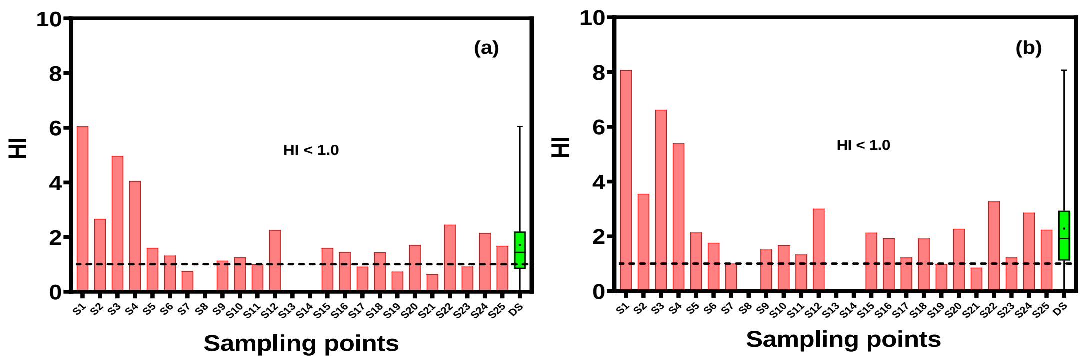


Fig. 6. HI of all heavy metals for (a) children and (b) adults.

3.5. Carcinogenic health risk assessment

TCR estimates the possibility of developing cancer due to overexposure to a specific carcinogen [43]. Due to the absence of CPSF, the TCR was calculated only for As and is presented in **Figure 7**. The mean TCR of As was 1.5E-04±1.1E-04 for children and 1.9E-04±1.4E-03 for adults, and it varied between 5.1E-05 to 4.8E-04 and 6.3E-04 to 6.0E-03 for children and adults, respectively. The TCR values of As in all the samples for children were within the permissible limit, but the As in 64% of the samples (DW1-DW6, DW9, DW10, DW12, DW15, DW16, DW18, DW20, DW22, DW24, and DW25) for adults surpassed the maximum threshold value of 10^{-4} recommended by USEPA [31]. The obtained result of TCR was supported by the study of Rahman et al. [4], where they reported that the TCR value of As for both adults and children in all samples exceeded the maximum risk limit. Recently, Rahman et al. [22] reported that the mean TCR values of As in drinking water samples collected from high schools in the Narail, Bagerhat, Sathkhira, Khulna, and Jashore district were above the safe limits.

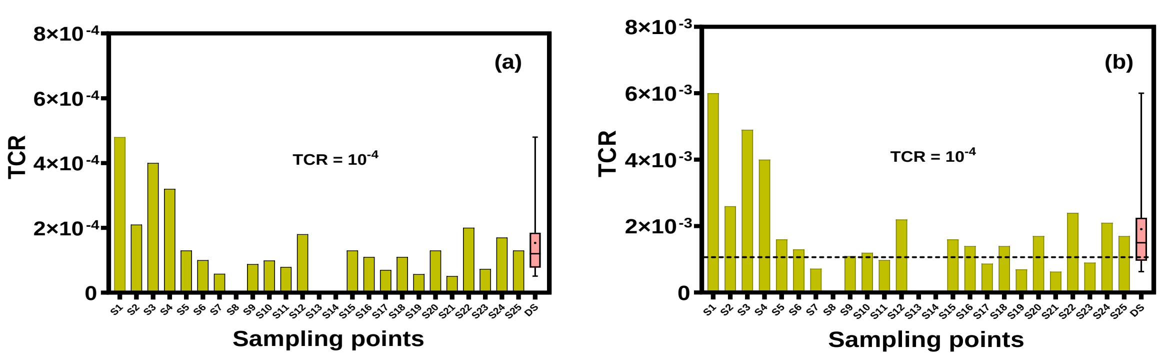


Fig. 7. TCR of As for (a) children and (b) adults.

In this study, As had a low contamination level in most of the drinking water samples but high TCR values for adults were observed mainly due to the high CPSF value of As recommended by the USEPA [44,45]. From a health risk perspective, the environmental quality standards and food safety standards of As may need to be improved [44,45]. As was previously mentioned, the BDS standard and CPSF value of arsenic is 50.0 μg/L [34] and 0.0015 $(\mu g/kg\text{-}day)^{-1}$ [31], respectively. By putting these values in Eq. 4, the TCR of the BDS standard was found to be 2.9E-03, which was also above the maximum risk limit ($TCR=10^{-4}$). This finding revealed that the TCR value of As in only 3 out of 25 samples (DW1, DW3, and DW4) for adults was greater than the TCR value of BDS. Hence, there was still a risk of As toxicity.

4. Conclusions

In this investigation, academic institutions were considered a source of heavy metal exposure to the students and adults because they spend several hours there and consume a sufficient quantity of water. Therefore, the concentrations of Zn, Cu, Fe, Mn, and As in the drinking water were determined, and the associated health risks to humans were estimated. The levels of toxic metals in most of the examined samples (except 52% for Mn and 12% for As) were within the permissible limit of the BDS standard and could be considered as almost safe for drinking purposes. The analysis of various health indices (EDI, THQ, HI, and TCR) suggested that Fe, Mn, Cu, and Zn in all the studied samples would not pose serious health effects, but As should receive more attention as a potential source of carcinogenic and non-carcinogenic risks. Therefore, regular monitoring of heavy metals in the drinking water should be periodically carried out. The overall findings of this study could help the authorities to create a proper plan to improve the drinking water quality, which could mitigate the possibility of developing associated health problems in the study population.

Acknowledgement

The authors are grateful to Chemistry Discipline, Khulna University for providing necessary laboratory facilities. The authors would like to thank Muhammad Sarwar Hossain, Assistant Professor, Khulna University, Khulna-9208, Bangladesh for his assistance during the preparation of the manuscript.

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